Exposure Due to Phone Calls of Other Users in Train Scenario

David Plets[1*], Wout Joseph[1], and Luc Martens[1]

[1]Department of Information Technology, Ghent university/iMinds, G. Crommenlaan 8 box 201, B-9050 Ghent, Belgium

[*]Corresponding author e-mail: david.plets@intec.ugent.be

The contribution of radio-frequent radiation originating from other people's devices to the total own whole-body absorption is assessed in a simulation study. In a Global System for Mobile Communications (GSM) macrocell connection scenario, the uplink of 15 other users can cause up to 15% of the total absorption when calling yourself and up to 100% when not calling yourself, while in a Universal Mobile Telecommunications System (UMTS) femtocell connection scenario, the contribution of the uplink of other users is negligible. When calling yourself, median total whole-body Specific Absorption Rates are reduced by a factor of about 400,000 when deploying a UMTS femtocell base station instead of relying on the GSM macrocell.

INTRODUCTION

Available exposure assessment studies quantify exposure originating from the base stations (BS) or from the user device, or even perform a global assessment of the exposure due to both BS and user device [1]. However, current research does not quantify the exposure originating from devices of other nearby users. In densely populated environments where wireless connection quality is bad, such as train wagons, it is expected that exposure originating from other users can make up a substantial part of the global exposure.

In this paper, this exposure will be determined for different scenarios in a train environment, using simulations, path loss measurements, and actual in-train measurements. A comparison is made between a Global System for Mobile Communications (GSM) macrocell and a Universal Mobile Telecommunications System (UMTS) femtocell deployment scenario. Further, the influence of the number of other users (0-15) is investigated. This study compares the different contributions that make up the total RF exposure of a human.

MATERIALS AND METHODS

Two train scenarios will be investigated, for which a 20 x 2.83 m train wagon with 66 passenger seats is considered (Fig. 1). The first scenario is a reference scenario, where persons in the train make a phone call and connect to a GSM macrocell base station at 900 MHz (GSM900), a typical current deployment. The second scenario considers a future deployment, in which persons on the train make a phone call and connect to an in-train UMTS FBS, which allows uplink transmit power control.

The considered user's whole-body Specific Absorption Rate (SAR) will be evaluated as a median over all locations in Figure 1 without a number (1-15) indicated on it (51 out of 66 locations remaining). The 15 locations with a number (1-15) in Figure 1 indicate the locations where other users are possibly present. These other users will contribute to the considered person's absorption at one of the 51 other seats. The total personal absorption SAR_{total} [W/kg] of a user then consists of:

- SAR_{own} due to the UL of the own mobile device (near-field source). SAR_{own} is determined by the transmit power of the own user device and by the near-field reference

SAR at the frequency of the UL traffic of the own user device (i.e., the near-field reference SAR for a transmitted power of 1W).

- SAR_{BS} due to all base stations (Macrocell Base Station (MBS) and/or FBS) in the area. SAR_{BS} is determined by the incident power density at the location of the user, due to the considered BS (MBS or FBS), and by the far-field reference SAR at the frequency of the downlink (DL) traffic of the considered BS (i.e., the far-field reference SAR for an incident power of $1W/m^2$).
- SAR_{other} due to the UL of all other users (far-field sources). SAR_{other} is determined by the incident power density at the user's location due to the UL of another user device, and by the far-field reference SAR at the frequency of the UL traffic of that other user device. The total number of other user devices accounted for in this paper will be 0, 1, 5, or 15. Other users become active in ascending order: for 1 other user, only other user 1 in Figure 1 is active, for 5 other users, other users 1 to 5 in Figure 1 are active, etc.

The two considered deployment scenarios in the train wagon are discussed hereafter. For the reference deployment (GSM900 macrocell scenario), it is assumed that a uniform DL power density (MBS to user) and UL power (own device to MBS) are observed over the entire train wagon. SAR_{MBS} due to the MBS and SAR_{own} due to the own user device are thus assumed to be spatially invariant throughout the train wagon. The median transmit powers and incident power densities for train users connecting to a GSM900 MBS are obtained from measurements along an actual train trajectory [2] and equal 12dBm or 15.85mW (accounting for the GSM duty cycle of 1:8) and $7.134 \times 10^{-3} \mu W/m^2$ (or -72 dBm), respectively. The power received from the base stations along the trajectory, and the power transmitted by the mobile phone were recorded with the application Azenqos, installed on a mobile phone.
For the future deployment (UMTS femtocell scenario), an FBS with an Equivalent Isotropically Radiated Power (EIRP) of -15 dBm is located inside the wagon as indicated with the purple dot in Figure 1. This low EIRP is sufficient to cover the entire train wagon. In-train users farther from the FBS will experience a lower SAR_{FBS} due to the decreasing FBS DL power density, but a higher SAR_{own} due to the increasing device transmit power towards the FBS (higher distance between FBS and device). Additionally, also an increasing SAR_{other} will be noticed for users farther from the FBS, since the other user devices surrounding the considered user will also be located farther from the FBS and will thus also transmit at a higher power and expose the considered user more. Although all in-train users are assumed to connect to the FBS in the second scenario, the MBS and SAR_{MBS} will still contribute to the user's total SAR. The transmit power of all user devices (own and other) towards the FBS is calculated according to [3]. The transmit power of another user device is then used in combination with the relevant path loss model to calculate the power density incident at the user, originating from the other user device. The reference SAR values required for the two scenarios are obtained from [4] and are listed in Table 1.

RESULTS AND DISCUSSION

Table 2 lists the results for the median whole-body SAR values in the train in the reference GSM900 macrocell scenario. The table lists the median value of SAR_{other} due to other users in the wagon for 0, 1, 5, and 15 other simultaneous users. The table shows that SAR_{MBS} (MBS DL) is always negligible compared to SAR_{own} (own device UL). As the number of other users increases, the contribution of SAR_{other} to the total exposure increases. For 5 other users, their median contribution is 3.5 μW/kg and increases to 10.8 μW/kg for 15 other simultaneously active users. The latter value is 17.8% of the value of SAR_{own} due to the own device (60.6μW/kg) and 15.1% of SAR_{total} (71.4μW/kg). When the considered user is not calling (SAR_{own} = 0 W/kg), SAR_{other} is always dominant over SAR_{MBS} and has a contribution of almost

100% to SAR_{total}: e.g., only other user 1 already induces a median SAR_{other} of 0.54 μW/kg, which is 17,622 times higher than SAR_{MBS} ($3.1x10^{-5}$ μW/kg). SAR_{total} remains at least 1,120 times below the ICNIRP guidelines of 0.08W/kg. Table 2 also lists the median whole-body SAR values in the UMTS femtocell scenario. SAR_{MBS} still has a contribution of about 19% to SAR_{total}. The median SAR_{FBS} ($1.1x10^{-4}$ μW/kg) dominates over the median SAR_{own} ($1.8x10^{-5}$ μW/kg) in the SAR_{total} value (contribution of almost 70%). The contribution SAR_{other} of other users is always negligible, even for 15 other users (0.8%), due to the very low transmit power of all users in the wagon and the relatively high median incident power density. SAR_{own} due to the own phone is around 11%.
When comparing the SAR values for the reference macrocell scenario with those for the femtocell scenario, the following observations can be made. For the UMTS femtocell scenario, the median value of SAR_{total} with 15 other users ($1.6x10^{-4}$ μW/kg) is more than $4.8x10^{8}$ times below the limit of 0.08 W/kg and 435,366 times below the maximal SAR_{total} value in the macrocell scenario (15 other users, 71.4 μW/kg). From the perspective of a non-user, installing a femtocell is already beneficial when just one other user starts making a phone call: user 1 causes a median SAR of 0.54 μW/kg when connecting to an MBS, which is 3,299 times higher than the median SAR_{total} ($1.6x10^{-4}$ μW/kg, see Table 2) due to MBS, FBS, own device, and 15 other active users when all are connected to a femtocell. This indicates the clear benefits of installing femtocell base stations in areas with a bad connection quality, also from an exposure point-of-view.

CONCLUSIONS

It can be concluded that for current deployments, the contribution of other in-train users is sometimes not negligible: 15 other users connected to a GSM900 macrocell base station induce median absorption rates up to 15% to the total absorption rate when calling yourself and a contribution of 100% when not calling yourself. A UMTS femtocell deployment in this environment drastically reduces the total absorption (when calling, around a factor 400,000) and makes the other users' contributions to the total absorption negligible (less than 1% of the total absorption). Future research will consist of considering the influence of the antenna orientation of the mobile device and of the assessment of 4G and 5G scenarios.

ACKNOWLEDGMENTS

This paper reports work undertaken in the context of the project LEXNET. LEXNET is a project supported by the European Commission in the 7th Framework Programme (GA n318273). For further information, please visit www.lexnetproject.eu.

REFERENCES

[1] Plets D, Joseph W, Vanhecke K, Vermeeren G, Wiart J, Aerts S, Varsier N, Martens L. 2015. Joint minimization of uplink and downlink whole-body dose in indoor wireless networks. BioMed Research International, special issue on Public Health Assessment of Impact of Heterogeneous Wireless Systems in Nonionizing Radiation Exposure. Article ID 943415, 9 pages, http://www.hindawi.com/journals/bmri/2015/943415/.
[2] Aerts S, Plets D, Thielens A, Martens L, Joseph W. 2015. Impact of a small cell on the RF-EMF exposure in a train. International Journal of Environmental Research and Public Health 12(3):2639-2652.
[3] Plets D, Joseph W, Vanhecke K, Martens L. 2013. Exposure optimization in indoor wireless networks by heuristic network planning. Progress in Electromagnetics Research-PIER 139:445-478.

[4] Lauer O, Frei P, Gosselin M, Joseph J, Röösli M, Fröhlich J. 2013. Combining near- and far-field exposure for an organ-specific and whole-body RF-EMF exposure for epidemiological research: a reference case. Bioelectromagnetics 34(5):366-374.

FIGURE 1: Map of train environment (20m x 2.83 m, 66 seats) with indication of the location of possibly active other users (1-15), and femtocell base station location (purple dot with EIRP of -15 dBm indicated inside). Median values are calculated over all 51 seats without a number (1-15).

TABLE 1: Reference SAR values (mW/kg) for far-field (FF, expressed per W/m² of observed power density) due to the downlink of a base station BS or the uplink of another user device and for near-field (NF, expressed per W of transmitted power) due to the uplink of the own user device.

TABLE 2: Median SAR_{MBS}, SAR_{FBS}, SAR_{own}, $SAR_{other'}$, and SAR_{total} values over 51 locations, for 0, 1, 5, and 15 other active users and contributions to SAR_{total} in GSM900 macrocell and UMTS femtocell scenario (see Figure 1).

Figure 1

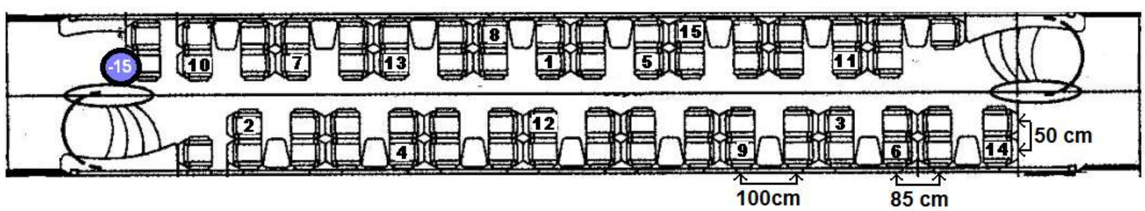

Table 1

SAR_{FF_ref} [mW/kg per W/m²]	SAR_{NF_ref} [mW/kg per W]
4.30 (GSM MBS DL @ 900 MHz)	3.85 (own UL @ 900 MHz to GSM MBS)
2.90 (UMTS FBS DL @ 2150 MHz)	4.95 (own UL @ 1950 MHz to UMTS FBS)
4.30 (other users' UL @ 900 MHz to GSM MBS)	
3.00 (other users' UL @ 1950 MHz to UMTS FBS)	

Table 2

#other users		0		1		5		15	
		[µW /kg]	*%total*	[µW /kg]	*%total*	[µW /kg]	*%total*	[µW /kg]	*%total*
GSM900 macrocell	SAR_{MBS}	$3.1x10^{-5}$	*0*	$3.1x10^{-5}$	*0*	$3.1x10^{-5}$	*0*	$3.1x10^{-5}$	*0*
	SAR_{own}	60.6	*100*	60.6	*99.1*	60.6	*94.6*	60.6	*84.9*
	SAR_{other}	0	*0*	0.54	*0.9*	3.5	*5.4*	10.8	*15.1*
	SAR_{total}	60.6	*100*	61.1	*100*	64.1	*100*	71.4	*100*
UMTS femtocell	SAR_{MBS}	$3.1x10^{-5}$	*18.9*	$3.1x10^{-5}$	*18.8*	$3.1x10^{-5}$	*18.8*	$3.1x10^{-5}$	*18.7*
	SAR_{FBS}	$1.1x10^{-4}$	*69.9*	$1.1x10^{-4}$	*69.7*	$1.1x10^{-4}$	*69.5*	$1.1x10^{-4}$	*69.2*
	SAR_{own}	$1.8x10^{-5}$	*11.2*	$1.8x10^{-5}$	*11.2*	$1.8x10^{-5}$	*11.2*	$1.8x10^{-5}$	*11.1*
	SAR_{other}	0	*0*	$4.1x10^{-8}$	*0.02*	$4.0x10^{-7}$	*0.3*	$1.4x10^{-6}$	*0.8*
	SAR_{total}	$1.6x10^{-4}$	*100*	$1.6x10^{-4}$	*100*	$1.6x10^{-4}$	*100*	$1.6x10^{-4}$	*100*